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TECHNICAL PROGRESS REPORT

CONTRACT DA-36-034-ORD-3296 RD

ORDNANCE CORPS PROJECT NUMBER — OMS 5010.1180 800.51.03

PREPARED FOR

U. S. ARMY ORDNANCE DISTRICT

PHILADELPHIA, PA.

UNDER

TECHNICAL SUPERVISION — FRANKFORD ARSENAL

CONTROL NO. A5180

DEVELOPMENT OF HIGH PERFORMANCE ROCKET MOTOR CASE

QUARTERLY REPORT NUMBER 21

Period - January 1, 1962 to March 31 1962

PRODUCT DEVELOPMENT DEPARTMENT
THE BUDD COMPANY
Philadelphia 32, Pennsylvania

THE Budd COMPANY

PHILADELPHIA 32. PA.

PRODUCT DEVELOPMENT

ENGINEERING
QUARTERLY PROGRESS REPORT NO. 21

Period: January 1, 1962 to March 31, 1962

Contract: DA-36-034-ORD-3296RD

Ordnance Corps Project No.: OMS-5010-1180800-51-03

ROCKET MOTOR CASE DEVELOPMENT

Control No. A-5180

Prepared by:

R. C. Dethloff

R. C. Dethloff

Approved by:

W. B. Dean

W. B. Dean, Manager
Product Development Department

Reviewed by:

B. Labaree

B. Labaree

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ABSTRACT

The objective of this program is to develop a solid propellant rocket motor case having the following characteristics:

1. A minimum diameter of 40 inches and a length to diameter ratio of 2:1.

2. An overall strength to weight ratio of 1×10^6 inch or more.

3. Utilize sheet or strip metal in condition of maximum usable strength requiring a minimum of post fabrication heat treatment.

The design objective is being attained through the following program:

1. Material investigation, evaluation and selection.

2. Weld joint evaluation of selected alloys.

3. Design, manufacture and hydrotest of 20 inch diameter chambers.

4. Design, manufacture and hydrotest of 40 inch diameter prototype chambers

Evaluation of twelve alloys has been completed. The following alloys were selected for the 20 inch diameter chambers based on the data obtained:

1. Ti 13V-11Cr-3Al alloy, cold rolled and aged to a minimum yield strength of 195,000 psi.

2. 20% nickel steel of a special analysis having 1.7 titanium and 0.5 aluminum in the composition. This material is cold rolled and aged to attain a minimum yield strength of 300,000 psi.

An additional evaluation is being conducted on the 20% nickel steel to determine the combination of cold reduction, aging temperature and aging time that will yield optimum tensile and fracture toughness values. Evaluation of the Ti 13V-11Cr-3Al alloy has been limited, due to the availability of data obtained from other contractors.

The 20 inch diameter chamber design uses 12 inch wide strip material, single thickness, butt welded, with the weld angle oriented 11 degrees to the direction of maximum hoop stress. The resultant normal stress in the weld, due to pressurization of the cylinder, will be lower than the as welded or as welded and aged strength of the

base metal.

The cylinder is helical butt welded in a fixture designed for this program. Strip is fed continuously through drive rolls at the proper helix angle. The TIG weld is made at the point where the incoming strip joins the adjacent wrapped section of the cylinder. Elliptical heads are cold formed using a newly developed proprietary sandwich draw technique.

Strip materials for the 20 inch diameter chambers were received during the latter part of first quarter 1962. Burst tests of the 20 inch nickel steel and titanium alloy chambers are scheduled for second quarter 1962.

INTRODUCTION

This is the twenty-first progress report covering the work being conducted under Contract DA36-034-ORD-3296RD by The Budd Company. The report includes the work accomplished during the quarterly period January 1, 1962 to March 31, 1962 and will serve as the monthly report for March, 1962.

Data on the evaluation of the 20% nickel mar-aging steel to determine the combination of cold reduction and aging temperature that will yield optimum mechanical properties, is included in this report. It was determined that a cold reduction of 60% to final gauge, followed by aging at 700^{o}, resulted in yield strength of 300,000 psi. Fracture toughness at this yield strength level, as measured by the K_{c1}, was 85,000 inch.

The results of T.I.G. welding evaluation of the 20% nickel of modified analysis are included. Effects of various aging temperatures on tensile values are shown. Aging welds at 600^{o}F - 700^{o}F yielded strengths suitable to the rocket case design.

A meeting was held at the Ordnance Materials

Research Office, Watertown Arsenal on March 2, 1962 to review the development program. It was suggested that the 40 inch diameter test chambers be deleted from the scope of work. It is felt that sufficient data could be obtained from the 20 inch tests, which are full metal thickness and will be tested at equivalent pressures to the 40 inch diameter, to fully establish the capability of the design.

Preparation for the manufacture of the 20 inch chamber continued during the quarter. Material for the heads and cylindrical sections of the test chambers was received late in March. We expect to test the chambers early in May, 1962. A discussion of the processing and testing of the 20 inch chambers is included in this report.

Sheet material, made from six AISI 4340 airmelt ingots made at Massachusetts Institute of Technology, was received from U. S. Steel Research Laboratory. A discussion of the processing and tensile test results is included herein.

PROGRAM REVIEW

A meeting was held on March 2, 1962 at The Ordnance materials Research Office, Watertown Arsenal to review current status of the contracts and discuss future objectives. Representatives of OMRO, Frankford Arsenal and The Budd Company were present.

It was recommended at this meeting that the 40 inch diameter prototype chamber be dropped from the program. The 20 inch diameter test chamber, having a shell thickness equivalent to the 40 inch chamber, the same weld helix angle, and a 2:1 length to diameter ratio would provide ample data to prove the design concept. Process and design variations associated with completely scaled down sub-scale test chambers would not be present. The need for additional tooling suitable for a 40 inch chamber is eliminated.

In place of the 40 inch chamber, it was recommended that the testing of 2 nickel steel, and 2 titanium alloy chambers, which have been in the program, be completed. This to be followed by a series of 20 inch hydrotest chambers (10 units) of one material to establish the reliability of the design. The ten additional chambers would be manufactured on presently available tooling.

20% NICKEL MAR-AGING STEEL

Effect of Cold Reduction and Aging Temperature on Mechanical Properties

Preliminary data have shown the advisability of using cold rolled 20% nickel steel for the fabrication of the rocket motor cases. The early evaluation of the alloy was accomplished using 0.032 inch strip which had been cold reduced 65%. The material was purchased from the Allegheny-Ludlum Steel Corporation.

The design of the 20 inch diameter chamber requires 0.040 inch gage strip with a yield strength from 300,000 psi to 310,000 psi. Test data have shown that this strength level is attainable using a variety of cold reductions and associated aging treatments. The purpose of the program discussed below was to find the optimum combination of cold reduction and aging temperature to produce material meeting the strength requirement and possessing the maximum obtainable fracture toughness.

The evaluation of the heat treatment of welds, as discussed in the next section of this report, shows the need for post weld aging treatments below 700°F. Therefore, it was also necessary to determine a combination of cold rolling and aging that would also be compatible with

the weld strength requirements.

Allegheny-Ludlum processed heat number 24022 for conversion to 0.040 inch, cold rolled 13½ inch wide strip. This steel had been vacuum induction melted and consumable electrode vacuum remelted. The analysis of the material is shown below:

C	Mn	P	S	Si	Ni	Al	Cb	Ti	Zr
.008	.008	.004	.005	.019	19.97	.47	.42	1.85	.018

B	Fe
.001	Bal.

A section of the hot band at a thickness of 0.275 inches was removed from the coil and shipped to the Allegheny-Ludlum Research Center at Brackenridge, Pa. To improve the surface condition the hot rolled strip was surface ground, reducing the gage to 0.250 inches.

At our direction, samples of the strip were cold reduced at various percentages of reduction to the 0.040 inch finish gage. All intermediate annealing was done at 1500°F, followed by pickling in straight 15% sulphuric acid.

The reductions used were 30%, 45%, 60% and 70%. It was specified that no intermediate reductions should be greater than the final specified reduction for each material sample. The sequence of cold rolling, as reported by Allegheny-Ludlum, is shown in Table No. 1.

All cold rolling was done in the original longitudinal direction of the hot band. The sample material was converted to 7 inch wide strips with a total length of at least 160 linear inches at each percent reduction. The material was oiled and paper wrapped for shipment to The Budd Company.

The evaluation of the mechanical properties was made using standard 2 inch gage length longitudinal tensile specimens, sub-scale 1 inch gage length transverse specimens, and standard 2 inch X 8½ inch center notched fracture energy specimens.

Groups of specimens from each percent reduction were single aged for 3 hours at 650°, 700°, 750°, 925° and 975°F. Each specimen group consisted of four longitudinal tensile specimens, two transverse tensile specimens, and three longitudinal fracture energy specimens. In addition,

COLD ROLLING OF 20% NICKEL STEEL

SEQUENCE OF ROLLING OPERATIONS

Heat No. 24022
Hot Band Gage 0.250 Inches

Annealed 1500°F (Prior to Rolling)
Pickled in 15% H_2SO_4

Cold Reduction %	Gage Inches	Cold Reduction %	Gage Inches	Cold Reduction %	Gage Inches	Cold Reduction %	Gage Inches	Cold Reduction %	Gage Inches
47	.133	70	.040	--	--	--	--	--	--
60	.100	60	.040	--	--	--	--	--	--
45	.137	45	.075	45	.040	--	--	--	--
30	.175	30	.122	30	.085	30	.057	30	.040

Material at the 0.040 inch thickness was left in the "as-rolled" condition.

Table 1

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two of each type of tensile specimen were tested in the "as rolled" condition. The testing of the longitudinal tensile specimens was shared by Allegheny-Ludlum and The Budd Company. A total of 200 specimens was prepared by The Budd Company for this evaluation. Figure No. 1 illustrates the specimen layout in respect to the 7 inch wide strip. The longitudinal tensile specimens were rough blanked, aged and finish ground. The sub-scale transverse tensile specimens were fully machined before heat treatment. The slots in the fracture energy specimens were machined after heat treatment using the electrical discharge method.

Before aging, all specimens were sub-zero cooled at -100°F for a period of at least 16 hours. The sub-zero cooling was accomplished by packing the material in crushed "dry ice". Specimens scheduled for a given aging temperature were heat treated at one time in the same closely controlled, recirculating air furnace.

A compilation of The Budd Company test data is shown in Table No. 2. The tensile test results represent an average of two specimens. The average of three specimens have been used to compute the fracture energy figures.

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CHECKED BY:		REPORT NO.
DATE: 4-9-62	LAYOUT OF TEST SPECIMENS — 7" STRIP —	PROJECT NO.

20% Nickel Steel

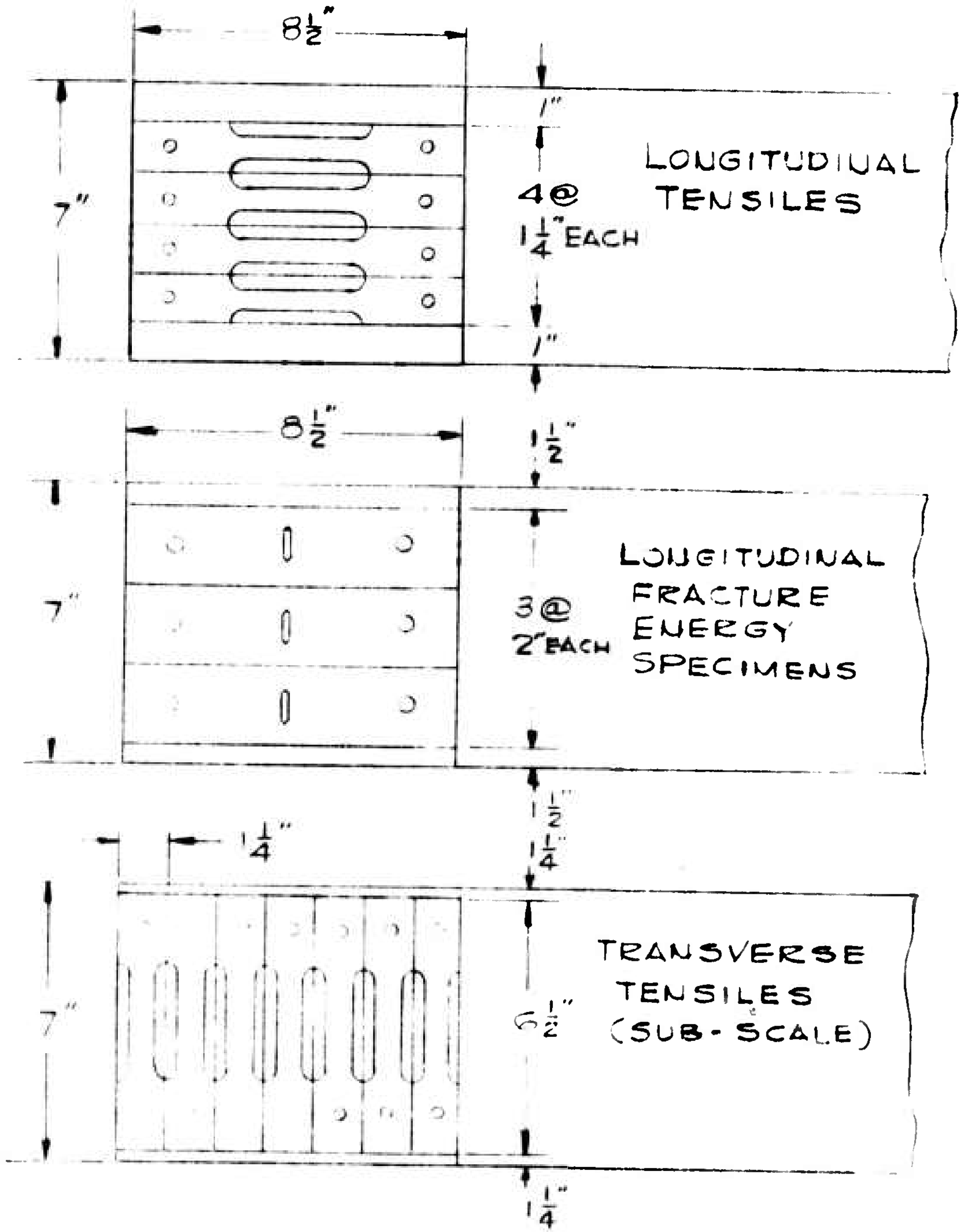

FIGURE 1

Tensile Properties of 20% Nickel Steel

- Various Degrees of Cold Reduction and Aging Temperatures -

% Reductions

Aging* Temp.		30			45			60			70		
		Y.S.	T.S.	F.E.	Y.S.	T.S.	F.E.	Y.S.	T.S.	F.E.	Y.S.	T.S.	F.E.
None	L	188	202	-	199	212	-	207	222	-	202	214	-
	T	194	223	-	182	207	-	199	225	-	204	228	--
650°F	L	255	255	128	264	264	160	280	281	135	277	277	128
	T	266	269	-	259	265	-	287	291	-	294	297	-
700°F	L	275	275	94	279	279	143	300	300	81	301	301	91
	T	286	290	-	290	293	-	317	318	-	-	326	-
750°F	L	305	306	74	316	317	58	329	332	49	337	339	52
	T	320	325	-	324	331	-	346	347	-	-	361	-
925°F	L	330	337	47	330	338	39	336	345	32	335	343	42
	T	353	361	-	355	364	-	353	364	-	348	360	-
975°F	L	287	301	69	297	310	69	289	308	45	302	316	40
	T	331	337	-	327	338	-	316	332	-	313	323	-

Y.S. - Yield Strength, 0.2% Offset, KSI
T.S. - Tensile Strength, KSI
F.E. - Fracture Energy, KSI $\sqrt{\text{inch}}$

*Aging Time, 3 hours

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Table 2

The tensile test data obtained by Allegheny-Ludlum from longitudinal tensile specimens agree favorably with our test results.

At the strength levels developed in this program, the ultimate strengths are only slightly higher than, or the same as the 0.2% offset yield strengths. Therefore, we have used the yield strength values in the plotting of the data.

Figure No. 2 graphically shows the longitudinal yield strengths, as developed by various combinations of cold reduction, versus the aging temperatures. Previous work had indicated the advisability of not investigating the aging temperatures above 750°F and below 925°F. Peak strengths as high as 350,000 psi with low ductility and toughness have been measured with material aged in the 800°F to 850°F range. The results of an investigation of 65% cold rolled strip of similar analysis, aged at temperatures from 750°F to 1000°F in 50°F increments, had been published in Report No. 18.

It is apparent from the data that the design requirement of 300,000 psi to 310,000 psi yield strength can be achieved by aging at temperatures below and above the

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DATE: 4-62	20% NICKEL STEEL LONG. YIELD STRENGTH VS. AGING TEMP. COLD ROLLED AS INDICATED PRIOR TO AGING	PROJECT NO.

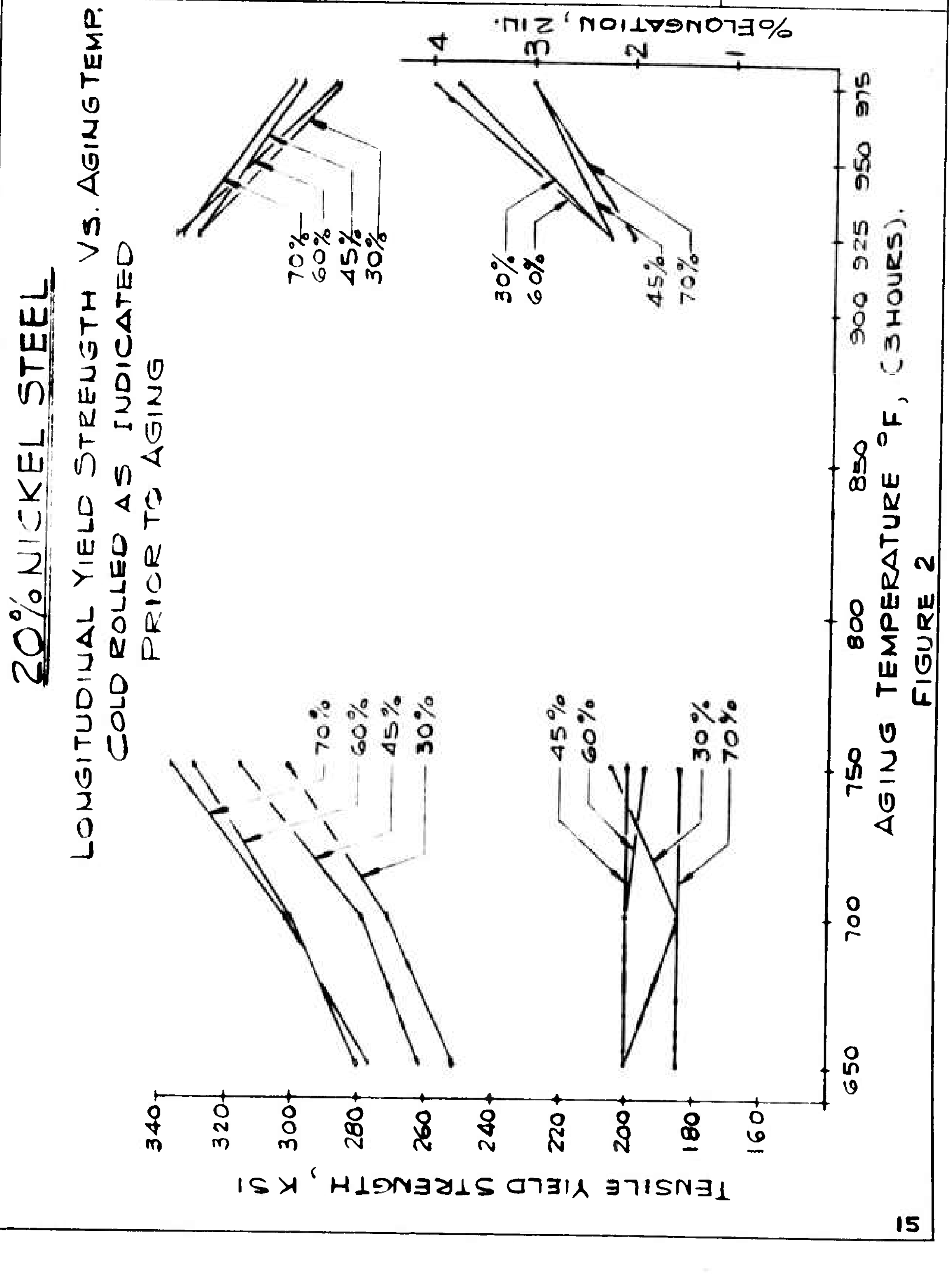

FIGURE 2

temperature of maximum response. Under-aging produced more variations of properties with the different degrees of cold reduction. The spread in values with various amounts of reductions is considerably less at the over-aging temperatures.

The fracture energy values, computed in terms of K_{cl} versus the yield strengths, are shown in both Figures Nos. 3 and 4. In Figure No. 3 the points obtained at the same aging temperatures, regardless of cold reductions, are grouped. Figure No. 4 shows the same curves with the points of similar cold reduction indicated. The fracture toughness appears to be in a linear relationship with the tensile yield strength, except where the material was aged at 975^{o}F. Although the ductility of material aged at 975^{o}F is improved and the strength is just under the 300,000 psi level, the fracture toughness values are low.

The best combination of properties for the rocket case design to be used was obtained with the 60% cold reduced material, which had been aged in the range of 700^{o}F to 750^{o}F. The optimum aging temperature for most efficient weld response is below 700^{o}F. However, with the base material strength being the most important requirement,

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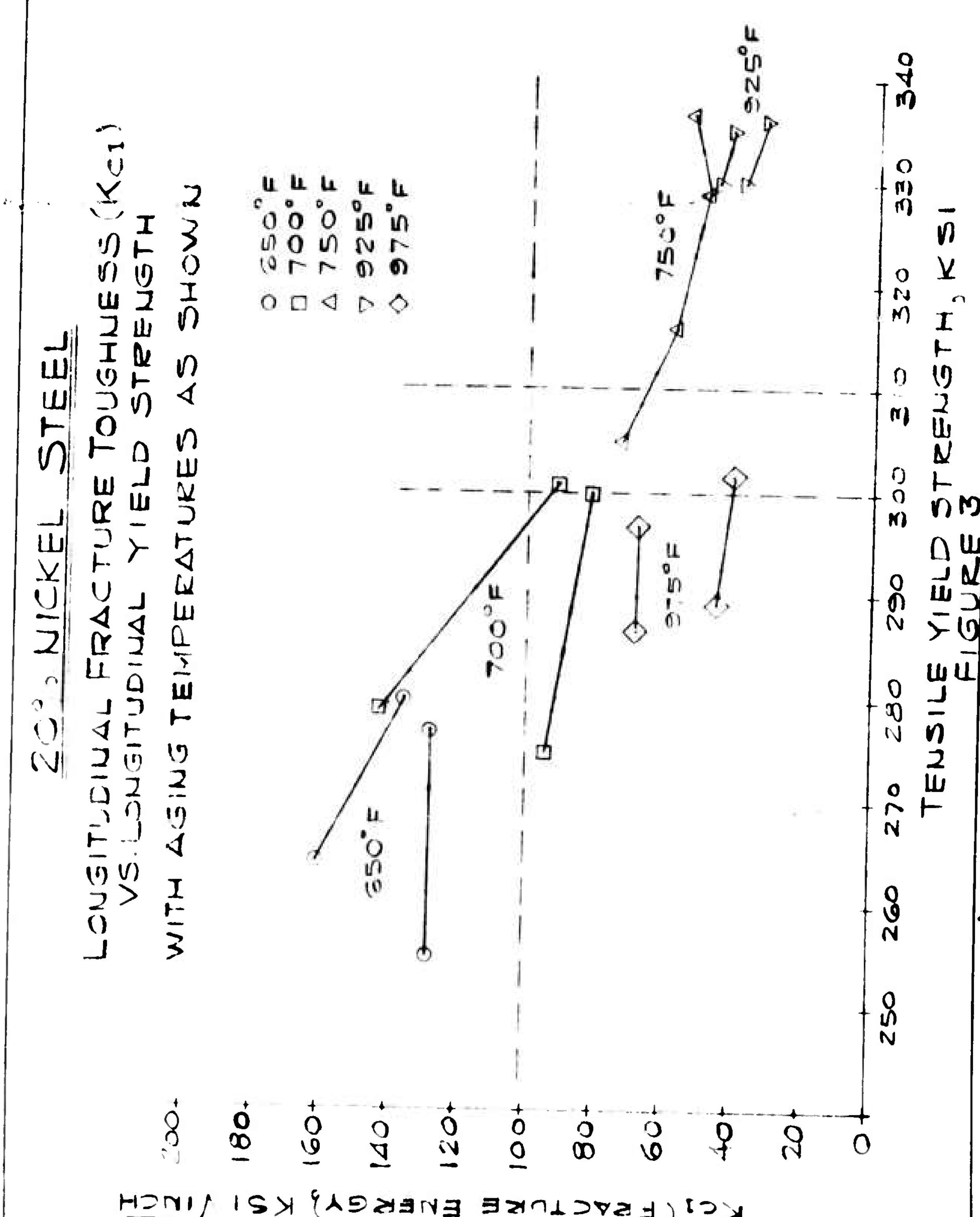

FIGURE 3

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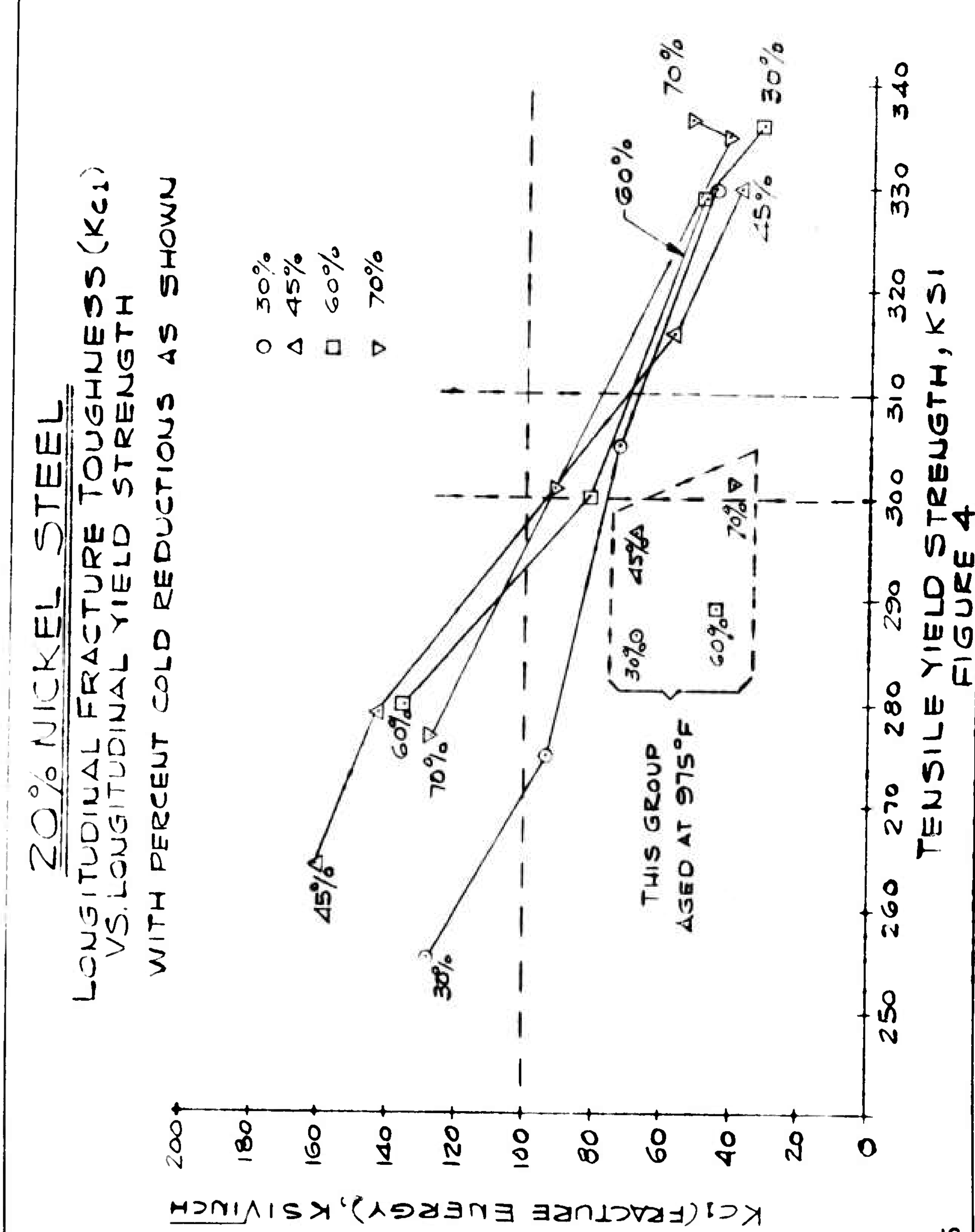

FIGURE 4

a slightly higher than optimum weld strength will be tolerated.

The aging of the 60% cold reduced strip in the 700°F temperature range develops from 300,000 psi to 330,000 psi. We will concentrate our future investigations in this temperature region and will most likely use an aging temperature close to 725°F.

The fracture toughness values measured in terms of K_{c1} (Figures Nos. 3 and 4) for the 60% reduced material aged between 700°F to 750°F, fall between 70,000 and 80,000 psi $\sqrt{\text{inch}}$. These are accepted as moderate values, but it is expected that this fracture toughness will be adequate when used with our rocket motor case design. For the convenience of the reader, the conversion of K_{c1} values to G_c values at various elastic modulii are shown in Figure No. 5. The G_c value represents the strain energy release rate.

<u>Welding of 20% Nickel Steel</u>

Report No. 18, issued in January, 1962, discussed the welding of the 20% nickel steel. At that time, the welding of the materials on hand was completed, but the mechanical properties of the joints had not been determined.

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DATE: 4-62	CONVERSION OF K_{c1} TO G_c	PROJECT NO.

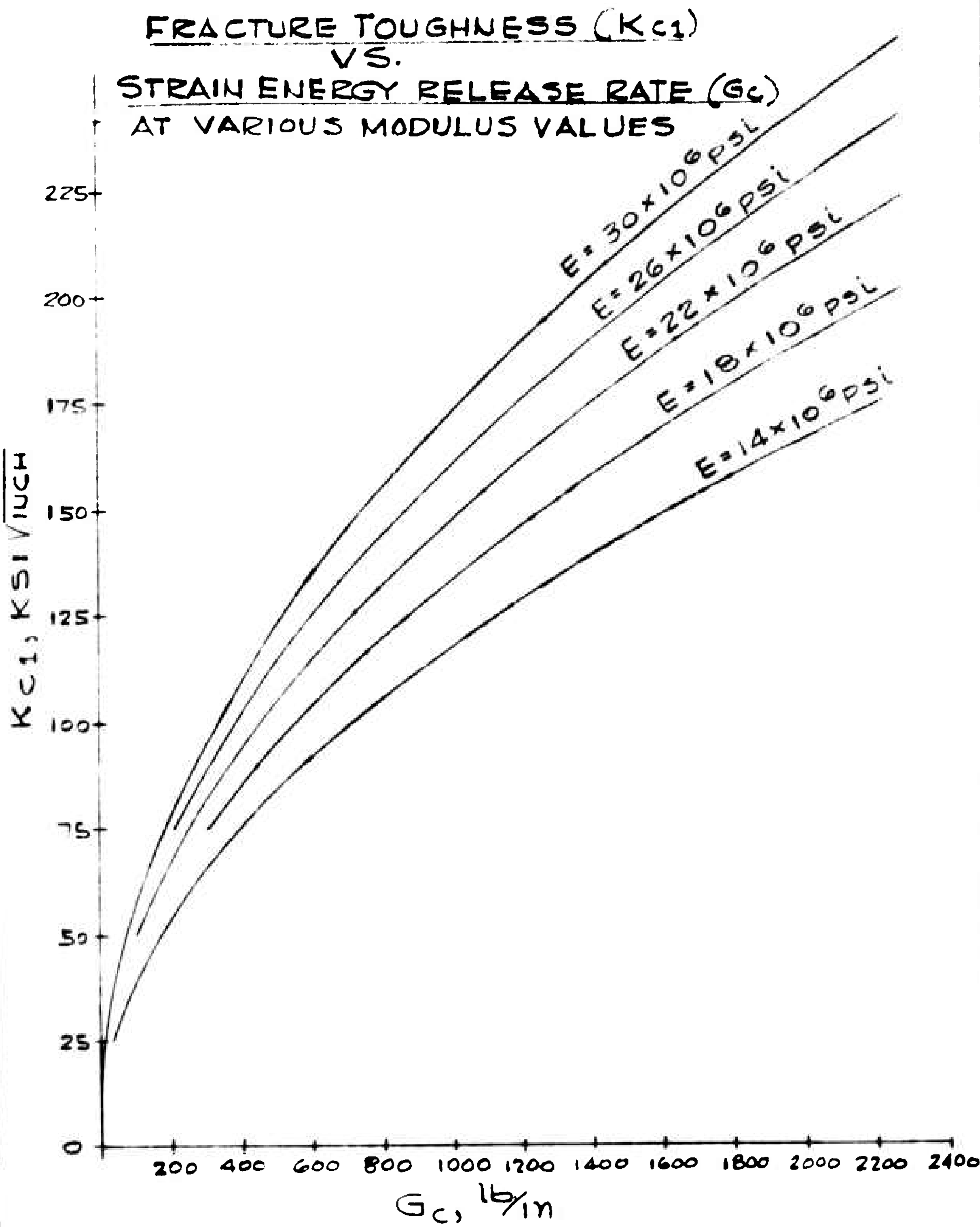

FIGURE 5

In this report the results of the tensile testing of the welds in various heat treated conditions are disclosed.

This phase of the welding evaluation has been exploratory in scope. In addition to obtaining a sound weld, we have investigated the effects of various thermal treatments, both before and after welding. When general parameters have been established, we will conduct a more specific investigation. The final work will be done with the actual production material, using the wire analysis selected for the production welding.

Although the welding schedules used for these materials were shown in Report No. 18, this information is repeated in Table No. 3 for the readers' convenience.

All weldments used for testing were dye-penetrant inspected and radiographed after welding. Any questionable areas of the weld were avoided in the layout of the tensile specimens.

<u>Annealed 0.075 Inch Sheet</u>

The 0.075 inch thick 20% nickel steel sheet was welded in both the annealed condition and in the mar-aged condition. The mar-aging in every instance was

TIG WELDING SCHEDULES

MATERIAL: 20% NICKEL STEEL - HIGH TITANIUM COMPOSITION

Gage	Material Condition	Weld Current Amps.	Arc Voltage Volts	Travel Speed In./Min.	Wire Diam. Ins.	Wire Feed In./Min.	Electrode Diam. Ins.	Chill Bar Spacing Ins.
0.032"	Cold Rolled	48-54	8-9	10	1/32	12	1/16	1/4
0.075"	Annealed	100-105	10	8½	1/32	18	3/32	1/2
0.075"	Mar-Aged 950°F	110	10	8½	1/32	18	3/32	1/2

Welding Conditions Common to Both Material Conditions and Gages:

1. Weld current is direct current, straight polarity (DCSP).
2. Matching analysis filler wire.
3. Back-up plate (dwg. No. 2434-0103), groove 0.050" X 0.250", with gas ports.
4. Metallic nozzle I.D. - 5/8" (#10).
5. 2% thoriated tungsten electrodes dressed to a conical point.
6. Electrode stick out - 1/2".
7. Copper chill bars.
8. Torch gas - argon at 30 CFH, trail gas - argon at 15 CFH, back-up gas - helium at 12 CFH.

Table 3

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preceded by sub-zero cooling at -100°F for 16 hours. The purpose of the work was to establish an aging temperature which would develop a yield strength across the weld joint of from 190,000 psi to 210,000 psi. This is the range of strength considered adequate for the rocket motor case design which is to be used. A maximum strength limit was stipulated to gain the greatest possible ductility of the joint.

Welded annealed sheet stock was tested "as welded" and after various aging treatments. Tensile data were obtained from specimens with the bead "as welded" and from specimens with the excess metal or reinforcement removed from the weld by grinding. The axis of the weld was perpendicular to the direction of loading. The yield strengths were calculated using a 2 inch gage length spanning the weld. Elongations were measured in percent over a 2 inch, 1 inch and ½ inch gage length. The data from this work are shown in Table No. 4.

The "as welded" strength was lower than would be obtained from annealed base metal. Failure occurred in the weld zone of all specimens, regardless of

TENSILE PROPERTIES OF ARC WELDS IN 20% NICKEL STEEL

Annealed
0.075 Inch Gage

Heat No. 23579-1
Matching Analysis Filler Wire

Condition	Yield Strength 0.2% Offset KSI	Ultimate Strength KSI	Elongation ½"	Elongation 1"	Elongation 2"	Location of Fracture
As Welded	121	132	15	7	4	Weld Zone
	121	137	18	8.5	5	" "
	117	133	17	8.5	5	" "
As Welded *	130	142	17	8	4.5	" "
	130	142	13	6	4	" "
	127	141	16	7.5	4.5	" "
	132	145	14	7	4	" "
Welded; -100°F; Aged 950°F, 3 hrs.	--	171	1.0	1.0	0.5	HAZ **
	--	220	2.0	1.0	0.5	HAZ **
	--	255	2.0	1.0	1.0	HAZ **
	--	256	2.0	1.0	1.0	HAZ **
Welded; -100°F; Aged 950°F, 3 hrs.*	--	242	2.0	1.0	0.5	HAZ **
	--	228	2.0	1.0	1.0	HAZ **
	--	263	2.0	1.0	1.0	HAZ **
	--	264	2.0	1.0	1.0	HAZ **

*Weld Reinforcement Removed.

** Heat Affected Zone.

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Table 4

whether or not the weld reinforcement was removed. The ductility values measured over a ½ inch gage length were reasonable and consistent.

Refrigeration at -100°F for 16 hours and aging at 950°F for 3 hours produced erratic results, particularly in welds without the reinforcement removed. The tensile strengths varied from 171,000 to 256,000 psi and the failures occurred in the heat affected zones. With the reinforcement removed, the fracture occurred in the same location and generally at the same strengths.

The effect of the aging of welds at other temperatures is shown in Table No. 5. After aging at 600°F and 700°F, the strengths are lower than the nominal aim of 200,000 psi, but the ductility is good. All fractures occurred in the heat affected zone. The specimens aged at 900°F for 3 hours and at 950°F for 8 hours proved to have low ductility which caused cracks to develop during the preparation of the specimens. The reduced section of the tensile specimen is rough blanked prior to finish grinding. The impact of of the die with the specimen developed the cracks in

TENSILE PROPERTIES OF ARC WELDS IN 20% NICKEL STEEL

Annealed
0.075 Inch Gage

Heat No. 23579-1
Matching Analysis Filler Wire

Condition	Yield Strength 0.2% Offset KSI	Ultimate Strength KSI	Elongation ½"	Elongation 1"	Elongation 2"	Location of Fracture
Welded; $-100^{\circ}F$; Aged $600^{\circ}F$, 3 hrs.	168	177	14	7	3.5	HAZ *
	167	174	8	4	2	HAZ *
Welded; $-100^{\circ}F$; Aged $700^{\circ}F$, 3 hrs.	187	192	12	6	4	HAZ *
	182	184 **	8	4	2.5	HAZ *
Welded; $-100^{\circ}F$; Aged $950^{\circ}F$, 8 hrs.	Low ductility, joint cracked in preparation of tensile specimens.					
Welded; $-100^{\circ}F$; Aged $950^{\circ}F$, 8 hrs.						

* Heat affected zone.
** Lack of fusion in root.

Table 5

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the region of the weld. The eight hour cycle was used in an attempt to improve the ductility to improve with longer aging cycles.

Mar-Aged 0.075 Inch Sheet

Test panels were also made of 0.075 inch material in the mar-aged condition. Prior to welding, the steel was aged at 950°F for 3 hours. The weld reinforcement was not removed from any of the welds. All the specimens were sub-zero cooled at -100°F before aging. After welding, tests were made of "as welded" specimens, and specimens which were re-aged at various temperatures. The tensile properties of these welds are shown in Table No. 6.

The "as welded" aged specimens developed approximately the same yield strength as "as welded" annealed material. (See Table No. 4.) The ultimate strength was less, with the ductility about the same magnitude. Re-aging at 600°F and 700°F produced strengths comparable with annealed-welded-aged material. Re-aging at 900°F produced one specimen of 212,000 psi ultimate strength and one of considerably lower strength. The lower strength specimen exhibited a course crystalline

TENSILE PROPERTIES OF ARC WELDS IN 20% NICKEL STEEL

Aged 950°F, 3 hrs.
0.075 Inch Gage

Heat No. 23579-1
Matching Analysis Filler Wire

Condition	Yield Strength 0.2% Offset KSI	Ultimate Strength KSI	Elongation ½"	Elongation 1"	Elongation 2"	Location of Fracture
As Welded	124	125	14	7	4	Weld
	122	124	14	7	4	"
Welded; -100°F; Aged 600°F, 3 hrs.	172	177	14	7	4	HAZ *
	175	179	12	6	3.5	HAZ *
Welded; -100°F; Aged 700°F, 3 hrs.	190	194	12	6	3.5	HAZ *
Welded; -100°F; Aged 900°F, 3 hrs.	--	212	2	1	1	HAZ *
	--	105 **	2	1	1	HAZ *
Welded; -100°F; Aged 950°F, 8 hrs.	--	278	2	1	1	HAZ *
	--	245	2	1	1	HAZ *

* Heat affected zone.
** Area of fracture shows very course crystalline structure.

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Table 6

structure adjacent to the weld. It appears that aging at this temperature develops a course precipitate which reduces the fracture toughness at the base metal-fusion zone interface. This condition promotes erratic behavior from specimen to specimen. Aging at 950°F for 8 hours produced high strength but the results with the limited number of specimens were inconsistent.

Cold Rolled 0.032 Inch Sheet

The 0.032 inch sheet used for welding had been cold rolled 65%. The material was welded in this condition, and the aging treatments, if any, were done after welding. This material was from the same heat of steel as the 0.075 inch sheet discussed above. Table No. 7 summarizes the data from this work.

Specimens in the "as welded" cold rolled condition exhibited much greater strength than comparable specimens of the annealed or mar-aged material. The strengths were similar whether or not the weld reinforcement was removed because fracture, in all cases, occurred in the heat affected zone. The elongation in the ½ inch spanning the weld was proportionately reduced.

TENSILE PROPERTIES OF ARC WELDS IN 20% NICKEL STEEL

Cold Rolled 65%
0.032 Inch Gage

Heat No. 23579-1
Matching Analysis Filler Wire

Condition	Yield Strength 0.2% Offset KSI	Ultimate Strength KSI	Elongation ½"	Elongation 1"	Elongation 2"	Location of Fracture
As welded	--	176	3	1.5	1.0	All specimens failed in the heat affected zone.
	--	180	4	2.5	1.5	
As welded, reinforcement removed	--	178	4	3	2	
	177	178	7	4	2	
Welded; -100°F; Aged 600°F, 3 hrs.	--	201	5	2.5	2	
	--	203	5	2.5	1.5	
Welded; -100°F; Aged 700°F, 3 hrs.	215	216	5	2.5	1.5	
	214	216	3	2	1.0	
Welded; -100°F; Aged 900°F, 3 hrs.	--	298	2	1.0	1.0	
	--	242	1.0	0.5	0.5	
Welded; -100°F; Aged 1000°F, 3 hrs.	313	322	3	1.5	1.0	
	314	323	3	1.5	1.0	
Welded; -100°F; Aged 600°F, 3 hrs. and 950°F, ½ hr.	--	313	3	1.5	1.0	
	--	310	1.0	1.0	0.5	
Welded; -100°F; Aged 950°F, 8 hrs.	--	75	1.0	0.5	0.5	
	--	92	1.0	0.5	0.5	

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Table 7

Aging at 600°F and 700°F produced attractive properties which fell within the range that we were attempting to meet. Erratic behavior was experienced again when specimens were aged at 900°F.

Very high strengths with moderate ductility were obtained by aging at 1000°F. At this temperature, about 97% joint efficiencies were obtained with ductility only slightly less than base metal ductility at this same strength level.

Double aging at 600°F for 3 hours and 950°F for ½ hour produced high strength, although lower than obtained by the 1000°F single age.

An 8 hour age at 950°F was tried. For some yet to be explained reason, the ultimate strengths of both specimens were extremely low, with almost nil ductility. No apparent defect in the welded zone could be found after fracture, and previous radiographs of the weld had shown the area to be sound.

20 INCH DIAMETER TEST CHAMBERS

Material Status

Strip and sheet materials for the 20 inch diameter chambers were received during March, 1962. The following is a summary of these receipts:

Budd Order	Description	Condition	Amount
GHP 4277	.040 X 13½ 20% Nickel Strip	C.R. 60%	175 Ft.
GHP 4328	.062 X 40 X 40 20% Nickel	Annealed	6 Sheets
GHP 4265	.060 X 13½ Ti-13V-11Cr-Al Strip	C.R.-Aged to 195,000 psi Y.S.	290 Ft.
GHP 4331	.071 X 40 X 40 Ti-13V-11Cr-3Al Sheet	Solution Annealed	6 Sheets

C.R. = Cold Rolled.

Discussion of Manufacturing Process

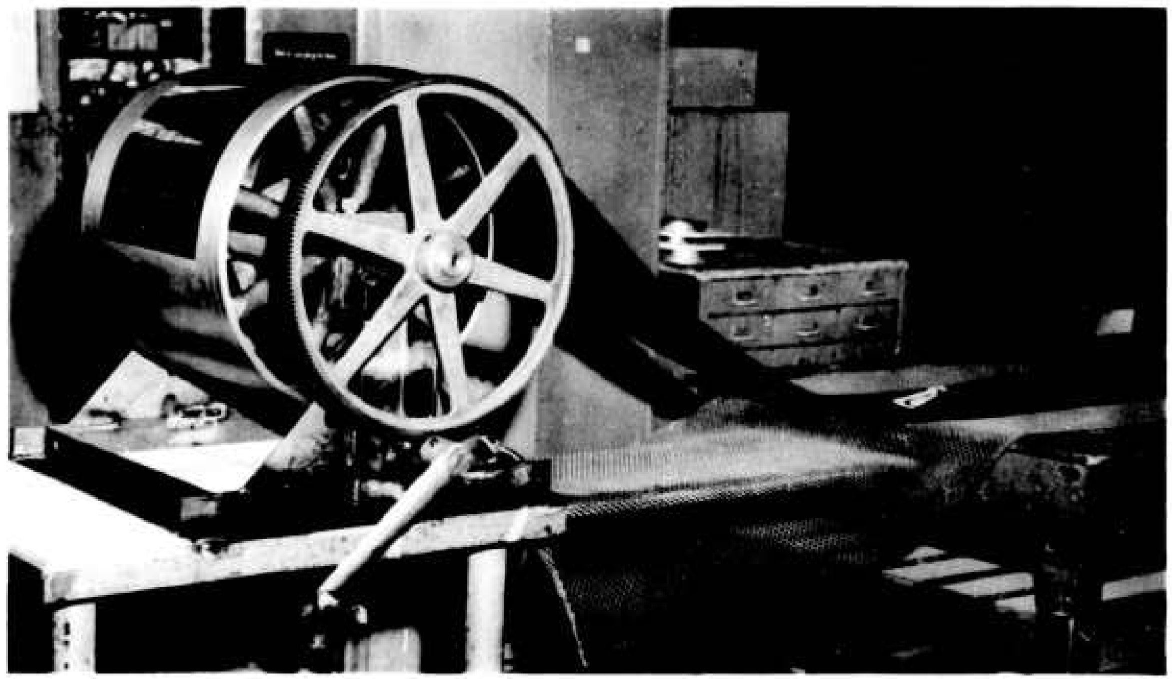
The manufacturing procedures set up on the 20 inch test chambers are aimed at reducing to the absolute minimum variations or discrepancies which can affect the performance of the case.

Material Preparation

The material selected was processed using higest quality base metal and alloying elements. In the case of the 20% nickel steel, vacuum primary melting and vacuum

consumable electrode remelting was employed. Since the alloys selected were recently developed, special handling during mill processing was required. Particular attention was paid to control of camber, thickness variations, surface finish, width, waviness, and edge conditions of the strip. These factors have a direct bearing on the ultimate quality of the chamber.

The dimensions of a helical welded cylinder are affected by the diameter of the cylinder, coil width, helix angle, and camber in the strip material. Of these, camber causes the greatest variation. A diametral taper in the cylinder is the result of this camber, which cannot be completely removed by sizing in low elongation ultra high strength materials. Data obtained during tryout of the welding fixture has indicated that an edge camber in excess of 3/4 inch in 30 feet of strip is unsatisfactory. In order to overcome this condition, the fixture shown in Figure No. 6 is employed. The coil is wrapped on the drum and aligned without stretching along a line at the centerline of the strip. The edges are then machined parallel in a lathe.



FIXTURE FOR RECOILING 12 INCH WIDE STRIP MATERIAL

EDGE MACHINING TO REMOVE CAMBER

Figure 6

Welding Cylindrical Sections

Welding of the cylindrical section is accomplished in a fixture designed specifically for the application. T.I.G. welding is automatic. Necessary chills, shielding gas and alignment of strip material is controlled as an integral part of the fixture. This fixture is illustrated and described in the text of Report No. 18, Figure No. 16.

Weld Inspection

Non-destructive inspection of welds is 100% on inside and outside surfaces of the cylindrical section and the joint of the elliptical head to the cylinder. Weld inspection includes the use of visual examination, aided by 10 power glass, flourescent penetrant inspection, and radiographic. Acceptance standards are summarized in Table No. 8.

Sizing The Cylindrical Section

Several methods for sizing the cylindrical section have been considered. Sizing is desired in the helical welded cylinder design to attain dimensional control, particularly in the weld area where local deformations, due to weld shrinkage, are present; and where dimensional

WELD INSPECTION
ACCEPTANCE LIMITS
20 INCH DIAMETER TEST CHAMBERS

VISUAL INSPECTION (10 X MAGNIFICATION) INSIDE AND OUTSIDE

Defect	Acceptance Limit
Voids	None
Cracks	None
Surface Checks	None
Burn Through	None
Arc Start Marks	None
Slugs	None
Weld Width	No abrupt change in weld width.
General	Weld line variation must be at minimum. No abrupt changes from weld line are cause for rejection. No sharp transition from weld bead to base metal.

FLOURESCENT PENETRANT INSPECTION

Defect	Acceptance Limit
Inside or Outside	No cracks acceptable. Other indications must be reviewed by Engineering prior to acceptance.

RADIOGRAPHIC INSPECTION

Defect	Acceptance Limit
Cracks	None
Incomplete Fusion	None
Incomplete Penetration	None
Sub-surface under-bead crater	.004 Diameter Maximum
Undercut	Length of any one undercut 0.30 inch accumulated length in any 36 inches of weld - 1.50 inches depth - maximum .01.
Voids, Porosity	Max. dimension of any one defect - .015. Min. distance between any two defects - .100.
Inclusions	Sum of longest dimensions of all defects per linear inch of weld - .060. Total linear porosity within .05 of a straight line between two voids - 40 units.

Table 8

variations in the strip material result in diametral changes from end to end of the cylinder. The relationship between the yield strength and ultimate tensile strength, plus low elongation values, requires a method of sizing where extremely close control is possible. Sizing must be accomplished within 1 to 1½% of the chamber diameter.

Consideration has been given to plug sizing method, and hydromechanical sizing. We have selected hydraulic sizing as providing the best control for working in the narrow ranges permitted by the load deformation diagrams of the alloys selected.

Figure No. 7 shows a schematic arrangement of the sizing unit. This unit comprises an outer sizing chamber, a rubber pressure bag and end closures. The cylindrical section to be sized is placed between the bag and the outer cylinder. Pressure is applied internally to the rubber bag sufficient to achieve a permanent deformation equal to approximately 1 to 2% of the cylinder diameter. The diameter of the outer sizing cylinder is determined by the spring back of the case shell, based on data obtained from load deformation curves of specimens taken from material in the same condition.

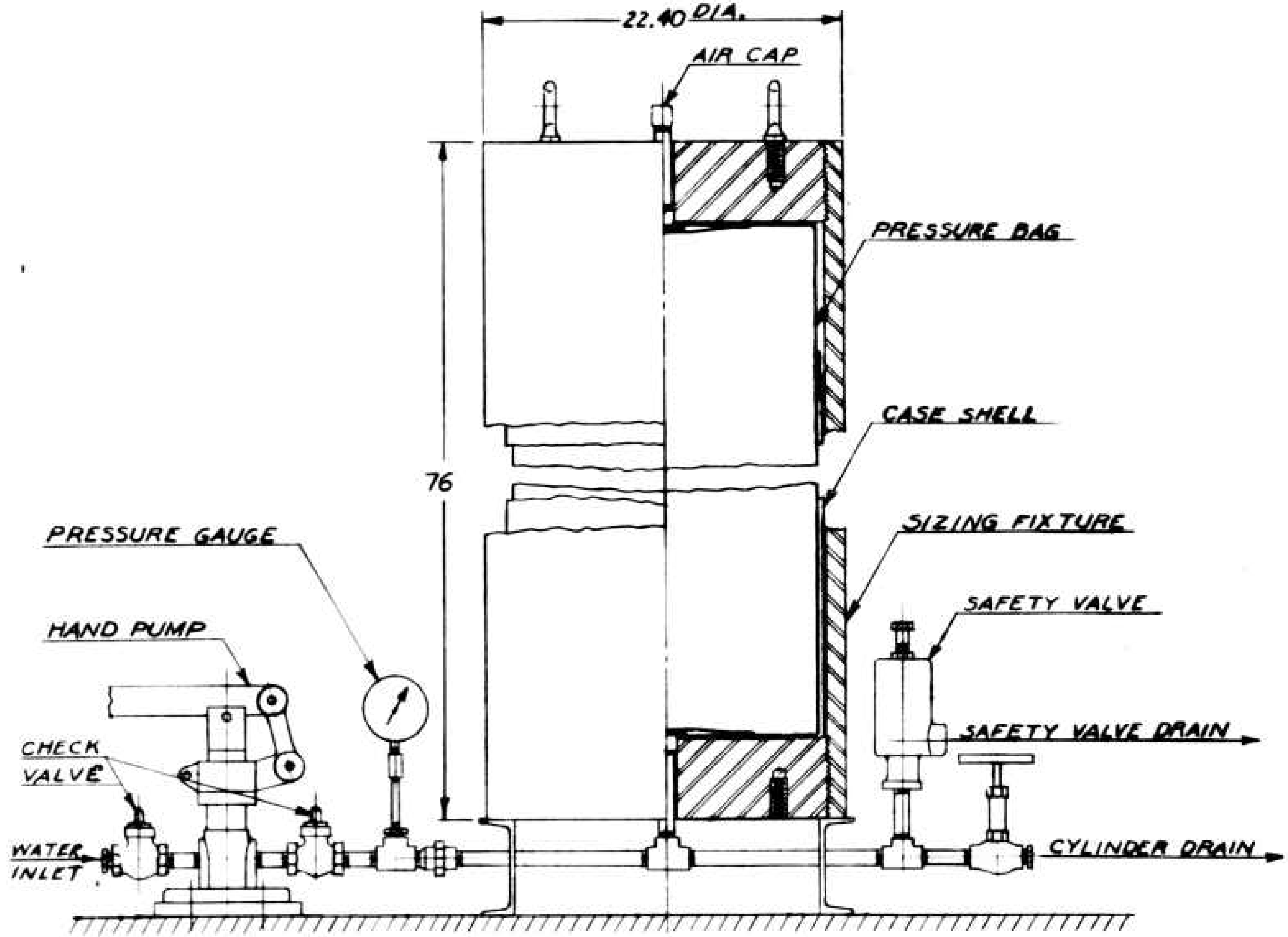


FIGURE 7

SCHEMATIC DIAGRAM - HYDRAULIC SIZING FIXTURE

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The sizing operation assures dimensional control on the entire cylinder. Local variations in the weld area caused by shrinkage during cooling of the weld and diametral variations in the cylinder due to coil width or helix angle changes during the welding process, are compensated.

Heat Treatment

20% Nickel Steel Chambers

The sub-zero cooling and aging treatments of the 20% nickel steel to develop full properties of the base metal and weld is an important part of the process. Figure No. 8 is a chart showing the sequence to be followed in the sub-zero cool and aging treatments. The elliptical head will be formed in the solution annealed condition, followed by a sub-zero cooling and aging treatment to a yield strength of approximately 290,000 psi. The helical welded cylindrical section is sub-zero cooled, sized, then aged at a somewhat lower temperature (750°F) to approximately 300,000 psi yield strength. The assembly of the elliptical head, and cylinder, plus doublers, are sub-zero cooled and aged at 650°F to improve the weld strength of the head to shell girth

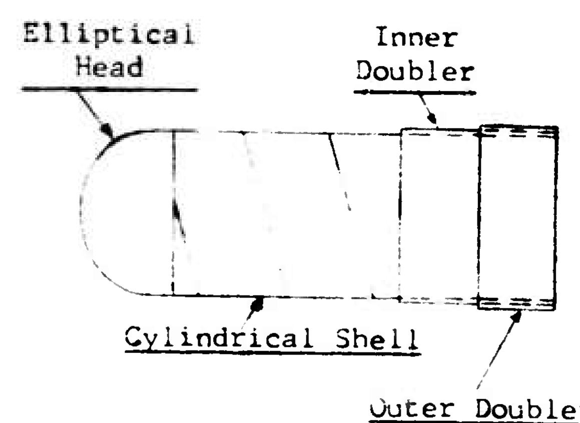
SUB-ZERO COOL AND AGING SEQUENCE

20 Inch Diameter Test Chamber
20% Nickel Steel (Hi-Titanium Analysis)

Elliptical Head	Cylindrical Shell	Cylindrical Shell
Sub-zero Cool -100°F. 16 Hrs. Age 950°F. 3 Hrs.	Helical Butt Welded Sub-Zero Cool -100°F. 16 Hrs. Prior to Sizing Base Metal and Weld	Age 750°F., 3 Hrs. After Sizing Base Metal and Weld

↓

Head - Shell - Doubler Assembly
Sub-Zero Cool -100°F.
Age 650°F.
3 Hrs.
Head - Shell - Weld

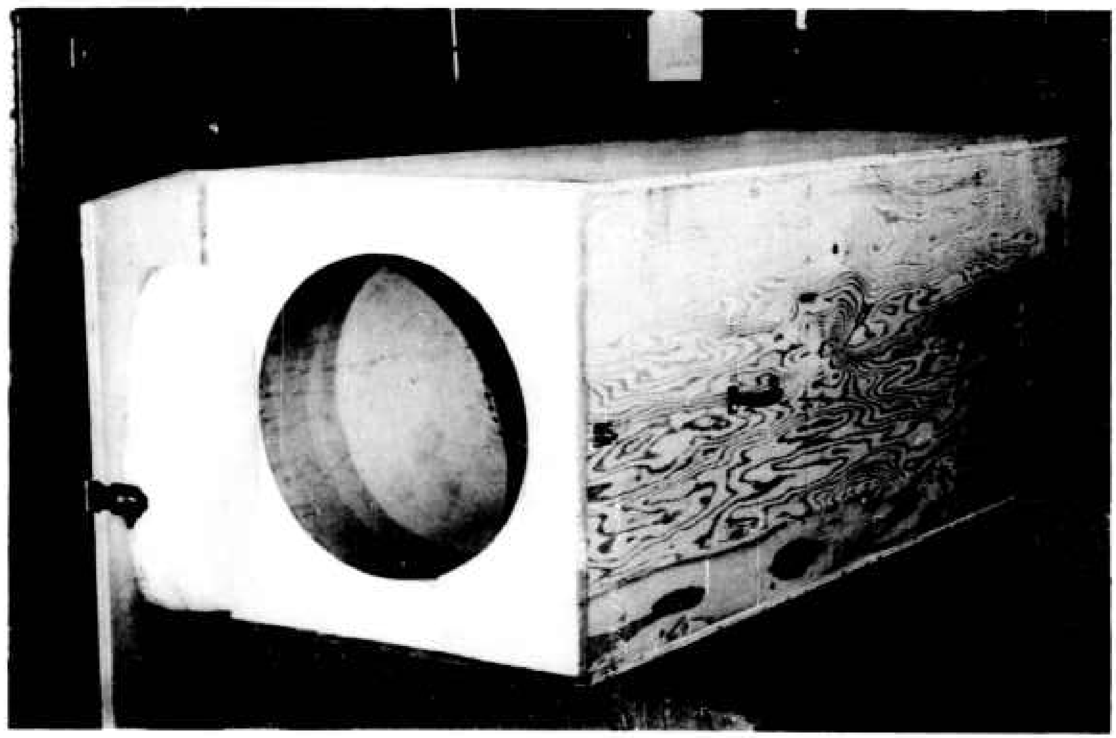


Key

Figure 8

joint.

The sub-zero cooling will be done in an insulated dry ice chamber, shown in Figure No. 9. Aging will be accomplished in a controlled argon atmosphere furnace. Control specimens will be attached to the chamber and detail parts to confirm the affect on properties of each sub-zero cool or aging treatment.



INSULATED CHAMBER FOR SUB-ZERO
COOLING 20% NICKEL ALLOY CYLINDERS AND
HEADS; 20 INCH DIAMETER TEST CHAMBERS

Figure 9

Ti 13V-11Cr-3Al Chambers

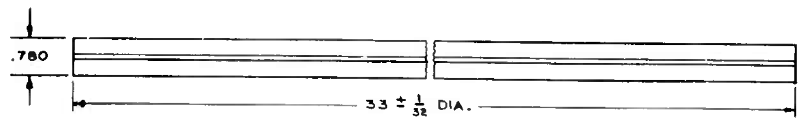
The titanium alloy heads are formed from material in the solution annealed condition. After forming, the head is re-solution annealed at approximately 1375°F. Following sizing operations, the head is aged to approximately 190,000 psi yield strength.

The titanium strip is cold rolled, plus aged to approximately 200,000 psi yield strength. No heat treatment will be required after helical welding or welding the elliptical head to the cylinder. The titanium head will be heat treated in a controlled argon atmosphere and control specimens will accompany each head through the treatment to verify material properties.

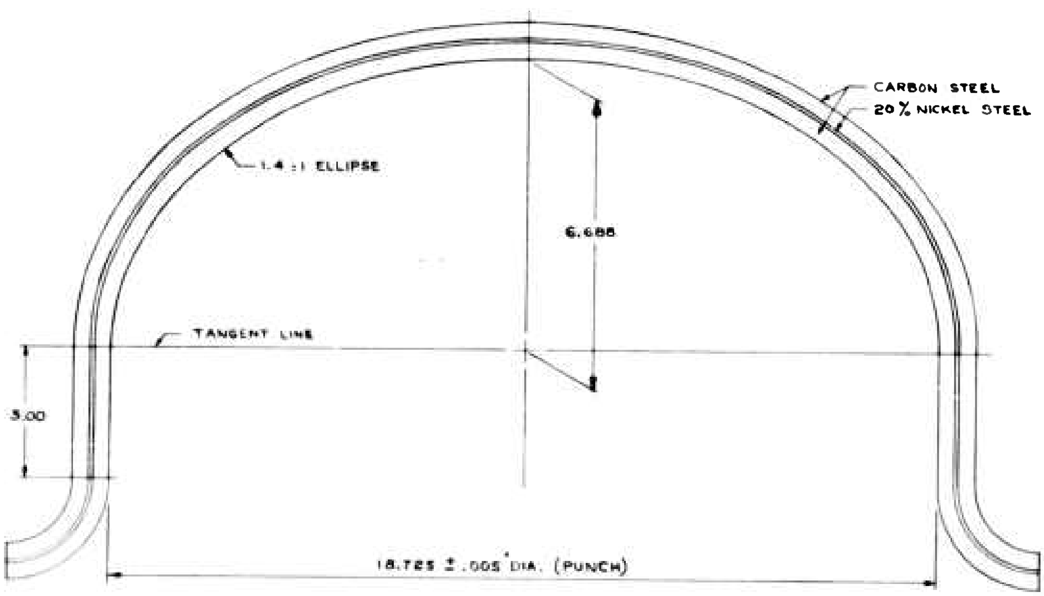
Elliptical Head Forming

A unique technique for forming large diameter thin wall elliptical and hemispherical heads has been developed by The Budd Company. The 20 inch diameter 1.4-1 elliptical heads for the 20 inch test chambers were drawn employing this method.

As shown in Figure No. 10, the head material is



PREPARED SANDWICH BLANK

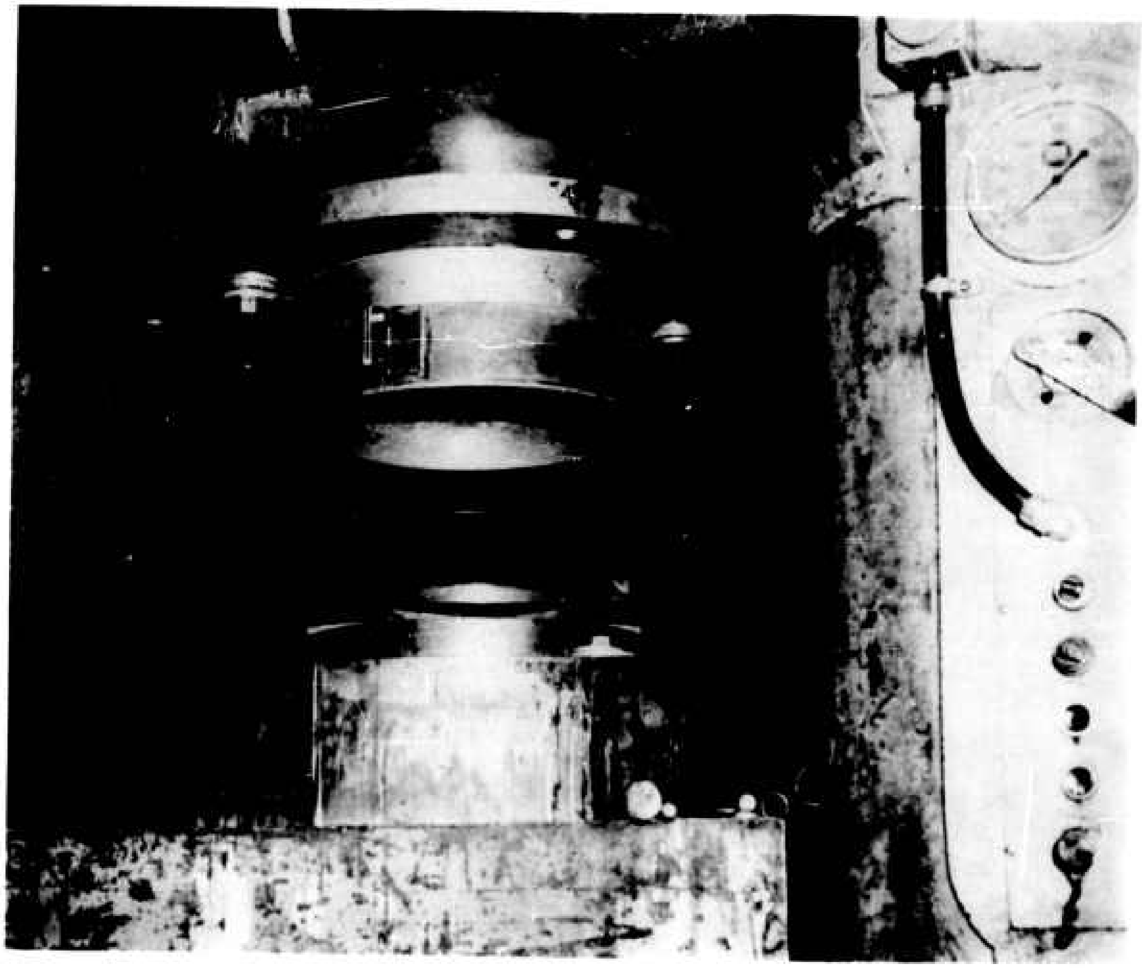


ARRANGEMENT OF SANDWICH BLANK FOR FORMING 20" DIA., 1.4:1 ELLIPTICAL HEAD

FIGURE 10

sandwiched between carbon steel cover plates. The three pieces are then welded around the periphery. During the forming operation in a hydraulic press, the carbon steel provides the effect of a radial compressive stress on the edge of the inner blank as the punch descends. Since the two cover plates are of sufficient thickness to be drawn without buckling, and the head blank is supported by the cover plates, the tendency of the inner piece to buckle is eliminated.

Accurate prediction of spring back allowance, based on a few specimens, is somewhat difficult in the new alloys being formed. Therefore we have provided a means for sizing the cylindrical section of the head. This is shown in Photograph Figure No. 11. The sizing operation permits accurate alignment of the head with the cylindrical section of welding.



DIE FOR SIZING CYLINDRICAL
SECTION OF 20 INCH DIAMETER
ELLIPTICAL HEAD

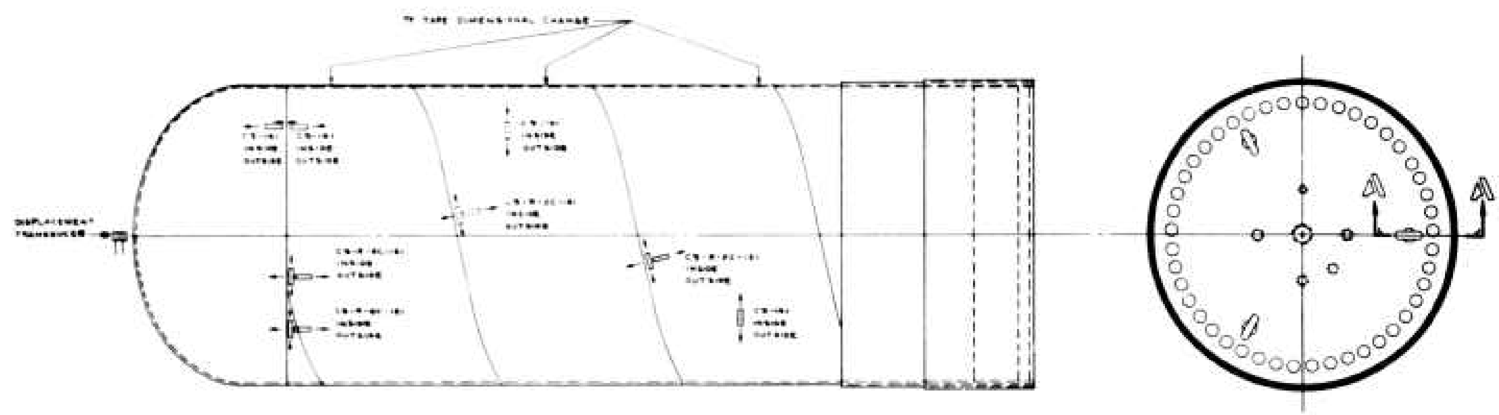
Figure 11

Hydrostatic Testing of 20 Inch Diameter Chambers

Preparations for hydrotesting two 20% nickel steel chambers and two titanium alloy chambers were made during the quarter.

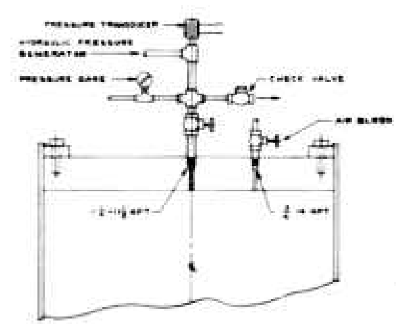
Figure No. 12, Drawing B2434-0251, shows the typical test arrangement. All the chambers will be tested to burst. The test will employ 24 strain gages, 12 located on the inside of the chamber and 12 on the outside. The gages will be placed as shown on the drawing.

It is planned to apply pressure in 200 psi increments until approximately 960 psi is reached. At this time the pressure will be reduced to zero where diametral and length dimensions will be checked to determine the presence of possible deformation. Pressure will then be applied to 800 psi and continue at 100 psi increments to burst. The calculated burst pressure is 1240 psi.

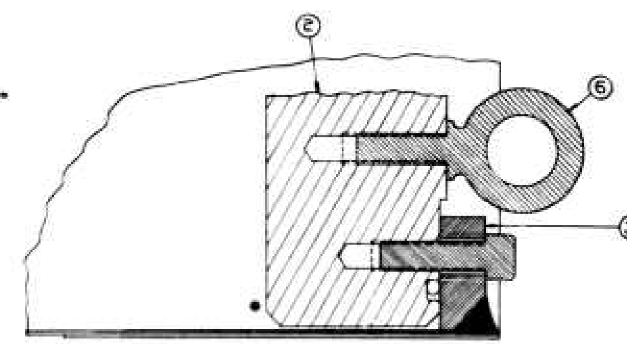


TEST NOTES

1. APPLY 12 INTERNAL STRAIN GAGES & LEADS IN LOCATIONS INDICATED ON DWG. THESE GAGES AND LEADS MUST BE APPLIED PRIOR TO INSTALLATION OF TEST PLATE ITEM (2) AND RETAINING RING ITEM (3).
2. APPLY 10 EXTERNAL STRAIN GAGES & LEADS IN LOCATIONS INDICATED ON DWG. [illegible]
3. TEST CHAMBER TO BE SUSPENDED VERTICALLY FROM EYEBOLTS ITEM (6).
4. PHOTOGRAPH TEST SET UP PRIOR TO START OF TEST AND AT CONCLUSION OF TEST. FOUR SHOTS OF CHAMBER AND 2 SHOTS OF INSTRUMENTATION.
5. FLUID FOR HYDRO TEST TO BE A NON-CORROSIVE LIGHT HYDRAULIC OIL (CITIES SERVICE [illegible] HYDRAULIC OIL [illegible] OR EQUIVALENT).
6. LEADS FROM INTERNAL STRAIN GAGES, HYDRAULIC OIL FILL AND BLEED LINES, PRESSURE GAGE WILL BE CONNECTED THROUGH TEST PLATE ITEM (2).
7. ALL PRESSURE GAGES AND OTHER INSTRUMENTATION SHALL BE PROPERLY CALIBRATED PRIOR TO TEST.
8. TEST PROCEDURE:
   - A. FILL CHAMBER WITH HYDRAULIC OIL, BLEED ALL AIR FROM CHAMBER AND LINES. SET ZERO READINGS ON PRESSURE GAGES.
     - 1. RECORD ZERO READINGS ON
       - (a) STRAIN GAGE RECORDERS
       - (b) PRESSURE TRANSDUCER
       - (c) VERTICAL DISPLACEMENT TRANSDUCER
       - (d) [illegible] π TAPE DIAMETER AT 3 POINTS ON CYLINDRICAL SECTION AS NOTED.
   - B. APPLY PRESSURE TO CHAMBER IN [illegible] P.S.I. INCREMENTS. AT EACH INCREMENT RECORD READINGS ON ALL STRAIN GAGES, PRESSURE TRANSDUCER, DISPLACEMENT TRANSDUCER.
   - C. AFTER [illegible] P.S.I. INCREMENT HAS BEEN REACHED, RECORD READINGS AT EACH 100 P.S.I. INCREMENT (SEE NOTE (D) BELOW).
   - D. AT [illegible] P.S.I. INCREMENT, RECORD READINGS, THEN DROP PRESSURE TO 0 PSI. RECORD ALL READINGS AND π TAPE DIAMETERS AT 3 POINTS INDICATED, AS A CHECK FOR PERMANENT SET.
   - E. APPLY PRESSURE TO [illegible] P.S.I. AND RECORD INSTRUMENT READINGS. CONTINUE AT INCREMENTS OF 100 P.S.I. UNTIL BURST. (CALCULATED BURST PRESSURE 1240 PSI.)
   - F. PHOTOGRAPH SETUP IMMEDIATELY AFTER BURST.
   - G. REPORT TEST RECORDINGS.



SCHEMATIC PIPING ARRANGEMENT



SEC A - A
ROTATED 90° CLOCKWISE (SCALE 1:1)

FIGURE 12

M.I.T. CONTROLLED INGOT SOLIDIFICATION STUDY

As discussed in previous reports, The Budd Company is participating with the Massachusetts Institute of Technology in the evaluation of two types of steel, which were made using a unique casting and solidification process. The steels, which are included in the investigation, are AISI 4340 and a high hardener analysis of the 25% nickel mar-aging steel. The steels were cast in molds which allowed the heat to be extracted from the bottom of the ingot only and not from the sides. This method produced a unidirectional grain structure aligned from top to bottom of the casting.

The ingot castings have been made at M.I.T. The conversion of the ingots to strip stock is being done at the Research Laboratory of the United States Steel Corporation at Monroeville, Pennsylvania. The general coordination of the program and heat treating and evaluation of the material is being done at The Budd Company.

Ingots have been cast using both the unidirectional solidification process and using the standard casting technique. The AISI 4340 steel has been melted and cast in both air and vacuum, whereas the 25% nickel steel has been melted and cast in vacuum only. The numbers of each type ingot to be used in the evaluation are shown as follows:

1. AISI 4340 Steel

   2 air - standard solidification

   4 air - unidirectional solidification

   2 vacuum - standard solidification

   4 vacuum - unidirectional solidification

2. 25% Nickel Steel

   2 vacuum - standard solidification

   4 vacuum - unidirectional solidification

In the past quarter a partial evaluation of the air melted AISI 4340 has been made. A summary of the air melted ingot identification numbers and the chemistry of the three heats are shown below:

Ingot No.	Type	C	Mn	Cr	Ni	Si	Mo
1-1 1-2	UDS * Standard	0.42	0.66	0.87	1.85	0.26	0.24
2-1 2-2	UDS * Standard	0.39	0.67	0.89	1.89	0.23	0.26
3-1 3-2	UDS * UDS *	0.39	0.73	0.86	1.89	0.27	0.28

* Unidirectional solidification.

NOTE: Two other heats using the same melting practice analyzed 0.002-0.003 P and 0.007-0.008 S.

The ingots produced by M.I.T. were approximately 4 inches in diameter by 4 inches long, weighing from 15 to 17 pounds. A thin slice was removed from the side of each casting for chemical and metallographic analysis by M.I.T.

Using conventional forging techniques, U. S. Steel forged the ingots into 2 inch thick slabs approximately 5-3/4 inches wide and 4-3/8 inches long. The ingots were forged in a direction perpendicular to the original centerline of the casting. None of the ingots was upset or forged in a direction parallel to the original centerline. A 1/16 inch layer was removed from the top and bottom surface of each slab before reheating for hot rolling.

The hot rolling of the slabs was done in two different directions relative to the original ingot centerline. Some were rolled with the rolling direction parallel, or aligned with the original ingot centerline. Others were rolled in a transverse direction. Figure No. 13 schematically illustrates the forging and rolling directions used. The slabs were rolled to a 6 to 6½ inch wide hot band 0.160 inches to 0.170 inches thick. All heating for forging or hot rolling was done in a protective atmosphere to minimize decarburization. Cover plates were also used to prevent excess loss of carbon.

FORGING AND ROLLING DIRECTIONS
4 INCH DIAMETER INGOTS

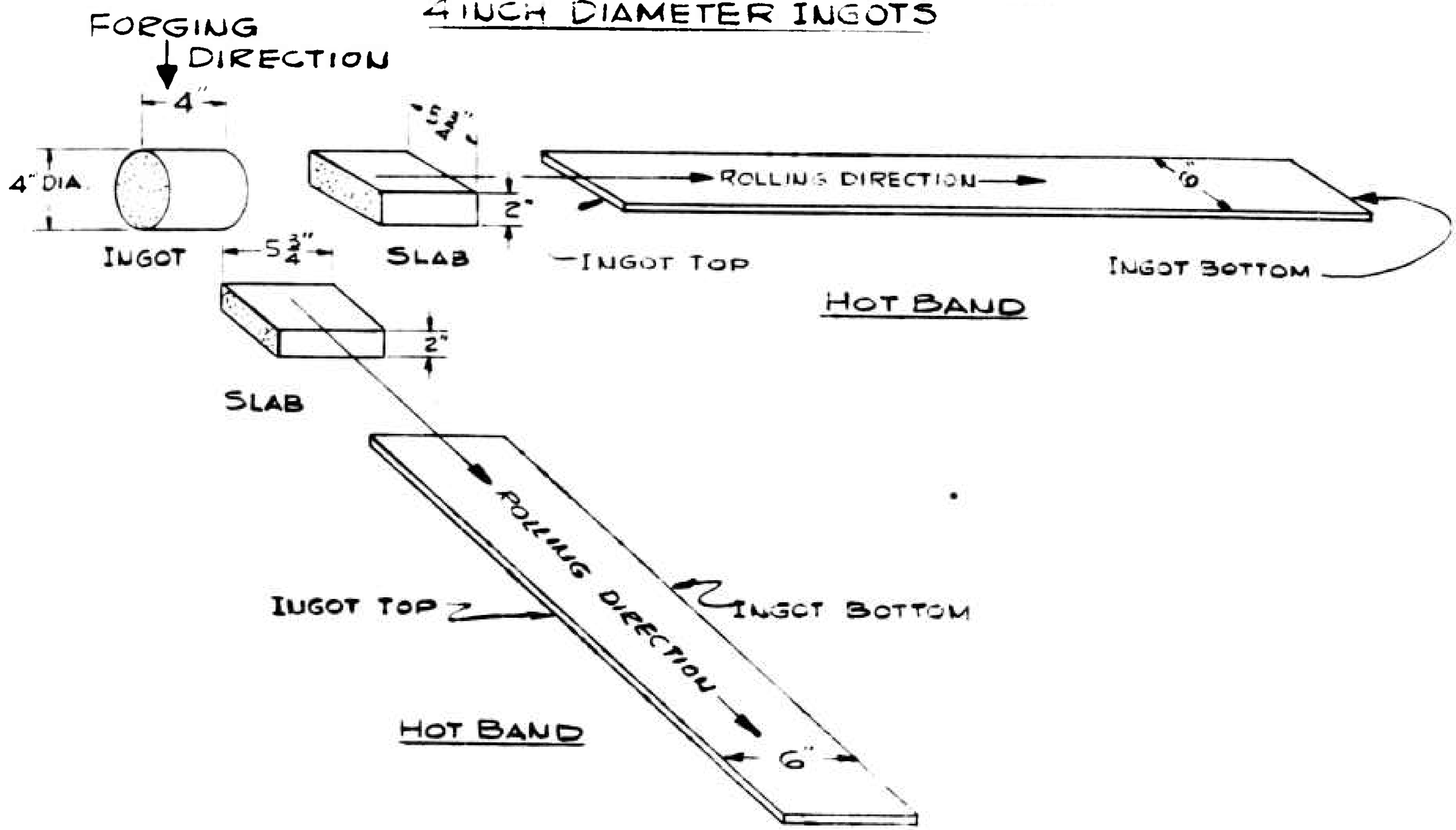


FIGURE 13

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After hot rolling, the bands were cut in half and given a spherodizing anneal. The annealed hot rolled stock was surface ground on both sides to a depth of 0.015 inches to remove all decarburization. A check of the decarburization depth before grinding had indicated considerably less than the 0.015 inches removed.

The hot band stock was cold rolled to 0.042 inches thick and shipped to The Budd Company without any further treatment. The strips were oiled and paper wrapped to prevent rusting.

As shown previously in the text, we received the product of three heats of the AISI 4340 air melted steel. Six ingots have been cast from these heats - two standard types and four unidirection types.

For ease of cold rolling, the hot bands were cut in half, which allowed for the cold rolling of twelve strips. The 6½ inch wide strips received varied from 42 inches to 58 inches in length.

The evaluation of the material was done using longitudinal and transverse tensile specimens, and longitudinal fracture energy specimens. The transverse tensile

specimens were subsize using a 1 inch by 3/8 inch gage length. For the evaluation of these six ingots, the following number and types of specimens were made:

30 Longitudinal standard 2 inch gage length tensile specimens

30 Transverse subscale 1 inch gage length tensile specimens

30 Longitudinal center notched fracture energy specimens.

The identification of the top and bottom of the ingots in respect to the final strip product was maintained by U. S. Steel during processing. The identification numbers were stamped at the "top" end of the longitudinally rolled strip. When the strips were cut in half, the respective sections were labeled "A" and "B". The transverse rolled strip was similarly identified; however, the edges of the strip represented material from the top and bottom of the original ingot. The half sections of the transverse rolled strip were marked "T1" and "T2".

There were three specimen groups taken from each longitudinally rolled strip of each ingot. Two groups were taken from each transverse strip. The location of these specimen groups in respect to the twelve test strips are shown in Figures Nos. 14 and 15. Each specimen group

SPECIMEN LAY-OUT DIAGRAM
LONGITUDINALLY ROLLED AISI 4340 STRIP

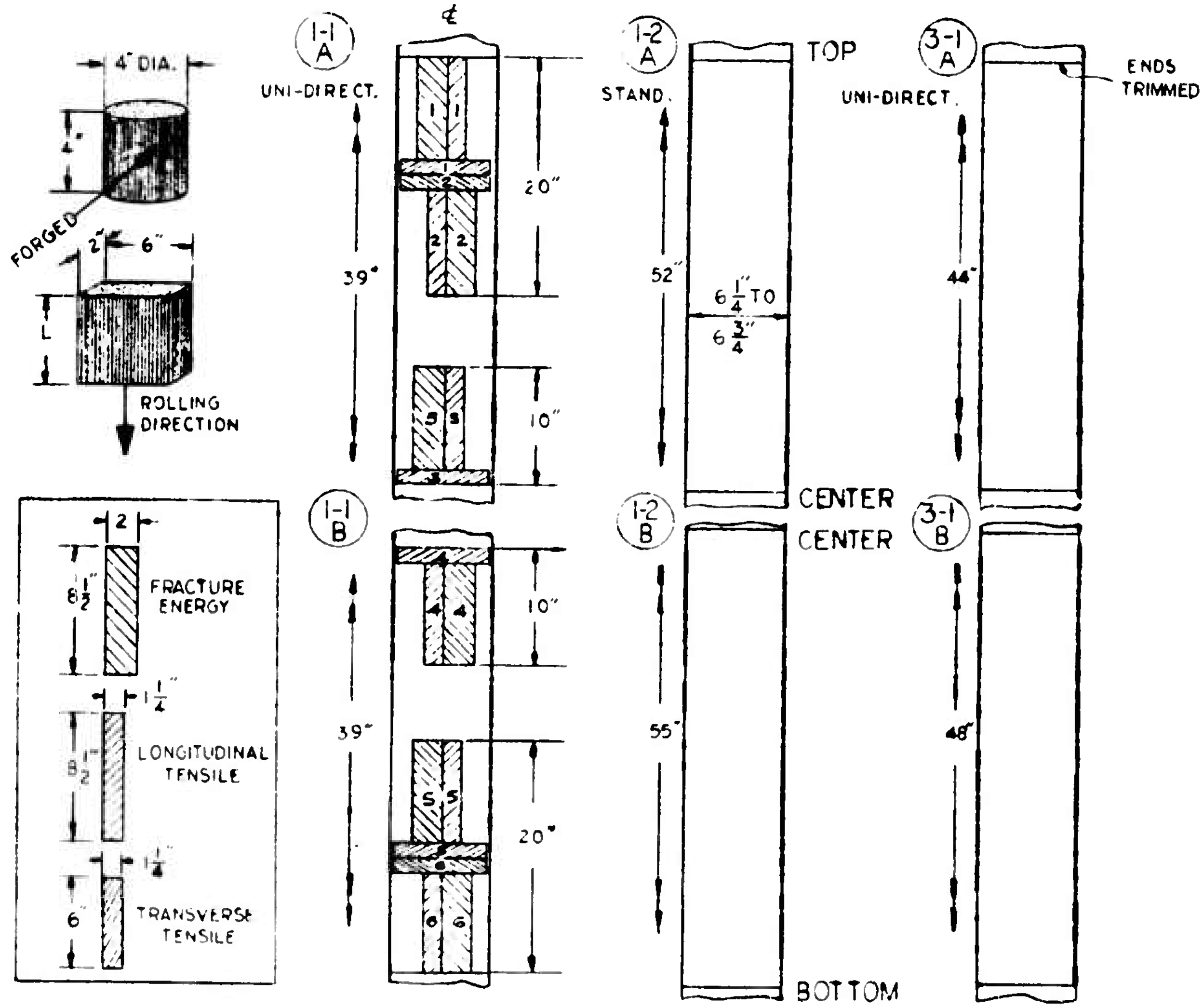

FIGURE 14

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SPECIMEN LAY-OUT DIAGRAM
TRANSVERSE ROLLED AISI 4340 STRIP

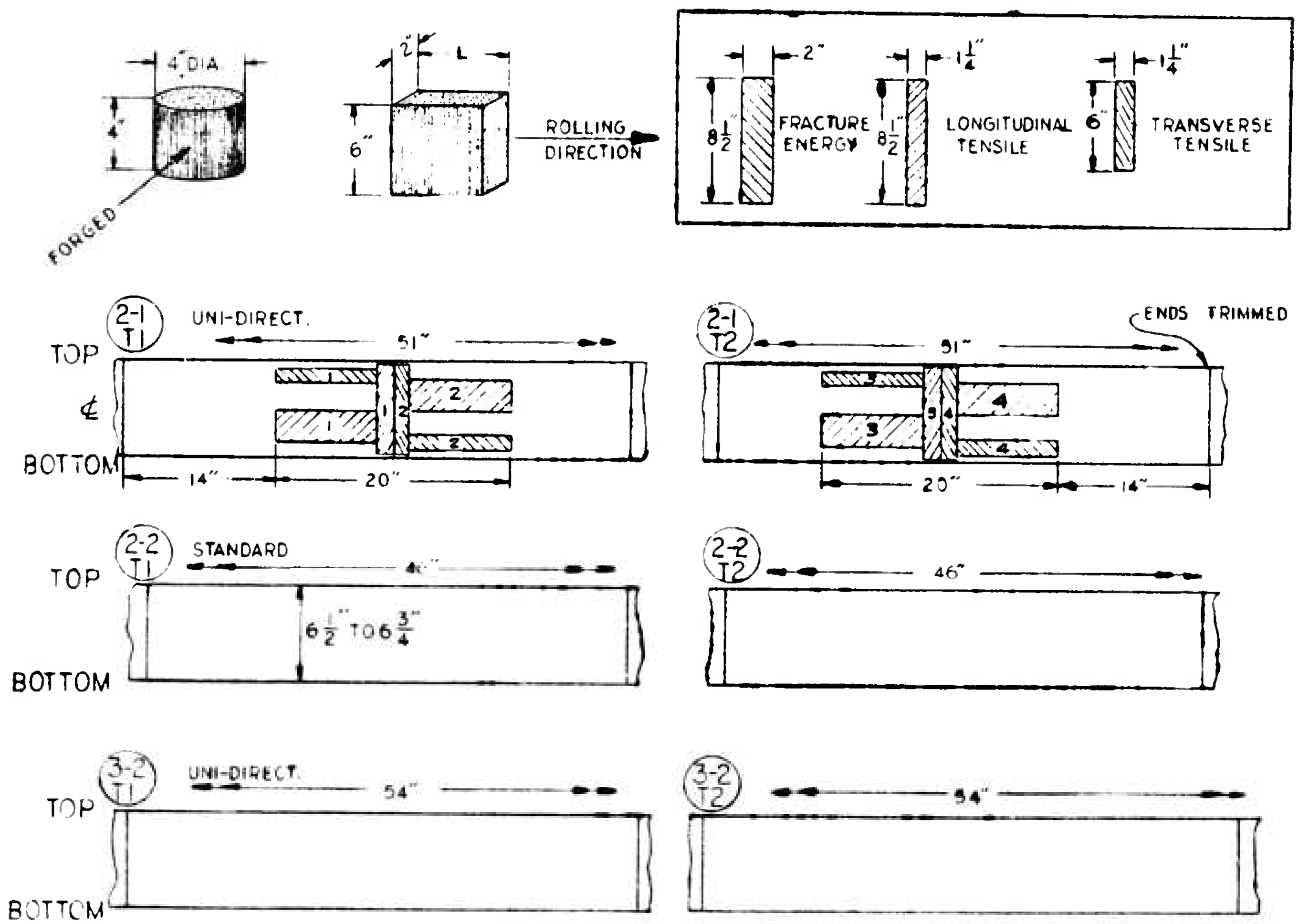

FIGURE 15

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consisted of two longitudinal tensile specimens, two transverse tensile specimens, and two fracture energy specimens. Similar specimens from each ingot are consecutively numbered.

The locations of the specimens in each group were selected to obtain the best possible sampling of the material in that area.

Each specimen has been identified using the following system:

A. The first two digits are the ingot numbers.

B. The letter in the third place indicates the specimen type.

   1. A - Longitudinal tensile.

   2. B - Longitudinal fracture energy.

   3. C - Transverse tensile.

C. The last digit is the individual specimen number relating back to the layout diagram.

Extreme care was used to accurately identify the specimens with the area that they represent. It was felt that this effort was necessary to make an intelligent appraisal of the subsequent test data.

Preliminary test specimen blanks were oil quenched from 1475°F and tempered at 200°F, 400°F and 600°F. The

$400^{\circ}F$ tempering temperature developed the most suitable tensile properties. The $200^{\circ}F$ temper was inadequate because of the low yield to ultimate tensile strength ratios. Tempering at $600^{\circ}F$ reduced both the yield and ultimate tensile strengths. It was considered important to maintain a high strength level to properly determine the fracture toughness of the material. The tensile values obtained at the various tempering temperatures are shown below:

	Yield Strength 0.2% Offset PSI	Ultimate Strength PSI	% El. in 2 Inches
$200^{\circ}F$	201,000	322,000	5
	201,000	308,000	4
$400^{\circ}F$	216,000	269,000	7
	228,000	267,000	7
$600^{\circ}F$	208,000	235,000	5
	212,000	238,000	5

The preliminary heat treatment was done in the Materials Research Laboratory of The Budd Company. The austenitizing at $1475^{\circ}F$ was done in an argon atmosphere. The specimens were tempered at $400^{\circ}F$ in air.

The balance of the specimens used for the evaluation proper were heat treated by an outside heat treating establishment using the same temperatures. A cracked hydrocarbon gas atmosphere was used with the carbon potential adjusted to the 0.40 C analysis. No decarburization was apparent on the fully heat treated material.

The edges of the longitudinal tensile specimens were finish ground after heat treatment. Because of fixture limitations the subscale transverse specimens were finish milled before heat treatment. The edges were lightly stoned after hardening. The slots in the fracture energy specimens were electrical discharge machined after heat treatment.

At the time of this writing, the longitudinal and transverse tensile test results are available. The fracture energy specimens have not been fatigue cracked and tested. These data will be available for the next quarterly report, at which time the entire evaluation should be completed.

The tensile test data are shown in Tables Nos. 9 through 14. No comments are made of these values, other than to say that the results are normal and consistent. The testing proceeded smoothly and no difficulties were experienced. Load deformation diagrams of all tests have been

TENSILE PROPERTIES OF AISI 4340 STEEL

Oil Quenched from 1475°F
Tempered at 400°F, 1 Hour

Air Melted
0.042 Inch Gage

Ingot No.	Type Solidification	Rolling Direction	Spec. No.	Spec. Direct.	Yield Strength 0.2% Offset KSI	Ultimate Strength KSI	% El. in 2 Inches
1-1	Uni-direct.	Long.	11A1	L	227	285	-
			2	L	224	288	4
			3	L	224	287	-
			4	L	217	293	4
			5	L	224	295	-
			6	L	224	290	4
1-2	Standard	Long.	12A1	L	225	293	6
			2	L	225	293	6
			3	L	224	294	5.5
			4	L	224	293	6.5
			5	L	224	293	7
			6	L	225	291	5

Table 9

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TENSILE PROPERTIES OF AISI 4340 STEEL

Oil Quenched from 1475°F
Tempered at 400°F, 1 Hour

Air Melted
0.042 Inch Gage

Ingot No.	Type Solidification	Rolling Direction	Spec. No.	Spec. Direct.	Yield Strength 0.2% Offset KSI	Ultimate Strength KSI	% El. in 2 Inches
1-1	Uni-direct	Long.	11C1	T	232	281	-
			2	T	232	282	3
			3	T	226	268	2.5
			4	T	229	281	3.5
			5	T	228	284	3
			6	T	229	278	3
1-2	Standard	Long.	12C1	T	226	284	4
			2	T	230	269	-
			3	T	229	290	5
			4	T	224	284	4
			5	T	223	285	5
			6	T	225	288	6

Table 10

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TENSILE PROPERTIES OF AISI 4340 STEEL

Oil Quenched from 1475°F
Tempered at 400°F, 1 Hour

Air Melted
0.042 Inch Gage

Ingot No.	Type Solidification	Rolling Direction	Spec. No.	Spec. Direct.	Yield Strength 0.2% Offset KSI	Ultimate Strength KSI	% El. in 2 Inches
2-1	Uni-direct.	Trans.	21A1	L	218	279	7.5
			2	L	219	279	7
			3	L	220	277	7
			4	L	220	277	7
2-2	Standard	Trans.	22A1	L	219	277	7
			2	L	219	276	7
			3	L	224	281	7
			4	L	220	276	7

Table 11

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TENSILE PROPERTIES OF AISI 4340 STEEL

Oil Quenched from 1475°F
Tempered at 400°F, 1 Hour

Air Melted
0.042 Inch Gage

Ingot No.	Type Solidification	Rolling Direction	Spec.	Spec. Direct.	Yield Strength 0.2% Offset KSI	Ultimate Strength KSI	% El. in 2 Inches
2-1	Uni-direct.	Trans.	21C1	T	216	280	4.5
			2	T	218	278	5
			3	T	207	260	6
			4	T	219	278	5
2-2	Standard	Trans.	22C1	T	220	273	4
			2	T	221	276	4
			3	T	222	277	4
			4	T	225	280	5

Table 12

The Budd Co.
4-62

TENSILE PROPERTIES OF AISI 4340 STEEL

Oil Quenched from 1475°F
Tempered at 400°F, 1 Hour

Air Melted
0.042 Inch Gage

Ingot	Solidification	Direction	Spec.	Direct.	Yield Strength 0.2% Offset KSI	Ultimate Strength KSI	% El. in 2 Inches
3-1	Uni-direct.	Long	31A1	L	215	287	5
			2	L	-	286	-
			3	L	218	288	6.5
			4	L	217	284	7
			5	L	219	288	6
			6	L	222	290	6
3-2	Uni-direct.	Trans.	32A1	L	223	286	6
			2	L	223	286	5.5
			3	L	223	284	6
			4	L	224	285	7

Table 13

The Budd Co.
4-62

TENSILE PROPERTIES OF AISI 4340 STEEL

Oil Quenched from 1475°F
Tempered at 400°F, 1 Hour

Air Melted
0.042 Inch Gage

Ingot No.	Type Solidification	Rolling Direction	Spec. No.	Spec. Direct.	Yield Strength 0.2% Offset KSI	Ultimate Strength KSI	% El. in 2 Inches
3-1	Uni-direct.	Long.	31C1	T	224	281	4
			2	T	217	282	4.5
			3	T	222	282	4
			4	T	221	284	-
			5	T	236	300	4
			6	T	221	280	4
3-2	Uni-direct.	Trans.	32C1	T	223	286	4
			2	T	226	-	-
			3	T	225	273	-
			4	T	227	279	4

Table 14

The Budd Co.
6-62

retained and shall be available for review, if necessary.

The next pages are copies of recent reports from Massachusetts Institute of Technology. These reports, by Dr. M. C. Flemings, summarize the work done at M.I.T. during the months of February and March, 1962.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAMBRIDGE 39, MASSACHUSETTS

9 March, 1962

MONTHLY PROGRESS REPORT NUMBER 7

PERIOD COVERED: 1 February, 1962 - 1 March, 1962

FROM: Massachusetts Institute of Technology
Division of Sponsored Research
Cambridge, Massachusetts

TO: The Budd Company
Product Development Department
Philadelphia 32, Pennsylvania
Attn.: Mr. R. C. Dethloff

CONTRACT NO.: Budd Order GHP-3912 under Prime Contract
DA-36-034-ORD-3296RD

TITLE: Solidification Control of Premium Quality Castings

WORK COMPLETED THIS PERIOD:

1. Nine heats of 4340 steel were vacuum melted and cast. All ingots cast were columnar; however, some difficulties have been experienced with chemical control of these heats.

2. Chemical analysis of the two previously cast 25 percent nickel steel ingots were received. The analyses were satisfactory. It is anticipated that the melting and casting of this alloy will be resumed during the next period.

M.I.T. Progress Report Number 7 Continued.

3. Evaluation of the ingots which have been produced has been continued.

WORK TO BE CONDUCTED DURING THE NEXT PERIOD:

1. Evaluation will be continued of ingots produced to date.

2. Additional heats will be vacuum melted and cast.

(Signed) Merton C. Flemings
Associate Professor of Metallurgy

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAMBRIDGE 39, MASSACHUSETTS

10 April, 1962

MONTHLY PROGRESS REPORT NUMBER 8

PERIOD COVERED: 1 March 1962 - 1 April 1962

FROM: Massachusetts Institute of Technology
Division of Sponsored Research
Cambridge, Massachusetts

TO: The Budd Company
Product Development Department
Philadelphia 32, Pennsylvania
Attn.: Mr. R. C. Dethloff

CONTRACT NO.: Budd Order GHP-3912 under Prime Contract
DA-36-034-ORD-3296RD

TITLE: Solidification Control of Premium Quality Castings

WORK COMPLETED THIS PERIOD:

1. Casting of the 4340 alloy vacuum melted ingots was completed this period. All ingots (4unidirectional and 2 "standard") were shipped to U. S. Steel for processing.

2. Macrostructural and chemical analyses on the above ingots were completed.

3. Microstructural and microradiographic examination of all ingots produced to date is continuing.

4. Two ingots of 25 percent nickel steel ingots were cast.

M.I.T. Progress Report Number 8 Continued.

WORK TO BE CONDUCTED DURING THE NEXT PERIOD:

1. Evaluation will be continued of ingots produced to date.

2. Additional heats will be vacuum melted and cast.

(Signed) Merton C. Flemings
Associate Professor of Metallurgy

WORK CONTEMPLATED FOR NEXT PERIOD:

Work during the next period will be directed toward the manufacture and hydrotest of two 20% nickel steel 20 inch diameter chambers. Material testing will be restricted to the control specimens used with in process heat treatment. It is expected that the testing of the 20 inch chamber will take place in early May, 1962.

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Quarterly Technical Progress Report No. 21, January - March, 1962
by R. C. Dethloff

Unclassified Report

Contract DA36-034-ORD-3296RD

The results of work performed during the quarter January, 1962 through March, 1962. These results include property data on 20% nickel steel, cold reduced 60%, and the effect of various aging temperatures, T.I.C. welding of 20% nickel steel, discussions of manufacturing process of the 20 inch test chambers, helical butt welded and tensile data on sheet material from M.I.T., Unidirectional cooled ingots.

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